Requirements for Remote Participation in Fusion Research Using Telecommunications:

A Report to the Fusion Power Coordinating Committee of the International Energy Agency by the Working Group on Remote Participation

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FOREWORD

The International Energy Agency (IEA) Fusion Power Coordinating Committee (FPCC) at its January 1996 meeting formed a Working Group on Remote Collaboration. The Working Group at its first meeting in response to its mandate to explore this issue for the FPCC proposed to develop a white (or issue) paper to discuss and clarify the requirements for effective remote collaboration using telecommunications. Further, recognizing that remote collaboration was a critical issue for fusion and science throughout the world, the Working Group took the opportunity afforded by the 1996 IAEA Fusion Energy Conference to hold a Workshop to illuminate the current fusion related activities being undertaken in this area around the world. As a result of that workshop and to foster an open dialogue throughout the fusion community the IEA Working Group has opened this draft white paper for comment from the world fusion community and encourages an exchange of views.

This draft white paper is an initial effort to refine the requirements for Remote Collaboration in Fusion Research using Telecommunications identified and developed by scientists in the U.S. Department of Energy's Magnetic Fusion Energy Sciences(MFES) programs at General Atomics (GA), Lawrence Livermore National Laboratory (LLNL), Massachusetts Institute of Technology (MIT), Oak Ridge National Laboratory (ORNL), and the Princeton Plasma Physics Laboratory (PPPL).

SUMMARY

Software and communications technology needs are defined such that experiments around the world will be accessible for increasingly sophisticated joint work and in appropriate situations operation from remote sites. For the immediate present, success of remote collaboration will depend on acquiring and developing technology infrastructure and management experience. But those actions will only happen if remote collaboration elicits enthusiasm for its benefits at the working research level. Paralleling that recognition must also be a serious commitment by program leaders to support a learning process based on incremental but increasingly sophisticated experience from current and future planned experiments.

In the future, the expectation is that some key large scale experiments such as ITER will involve fundamental partnerships where the experimental planning and actual day to day operational direction of a facility will be shared among the participants. Remote collaboration can be an essential building block to strengthen the partnership. There will be some limits, however, to the application of remote participation to large scale projects. These limits are likely to arise in response to the demands of domestic licensing of the host site and international agreements, rather than constraints imposed by costs, lack of available communication technology or operational management requirements. Achieving a meaningful level of collaboration for projects of this scale, also requires formal governmental and programmatic consensus among the partners.

While collaborations on large scale facilities may ultimately be a critical goal, over time the more pervasive benefit of the remote collaboration approach is likely to arise from broadly enhancing the scientific and technical productivity of many of the world's fusion physics and technology experiments, as well as supporting theory/modeling initiatives. Therefore, any comprehensive effort to support fusion remote collaboration also has to account for the reality that partnerships will come on different scales, and involve, in an appropriate manner, the resources of fusion contributors from throughout the world.

Reinforcing the impetus toward the broadest possible integrated world participation is the fact that fusion is a complex undertaking and the world fusion community cannot afford to neglect new and emerging as well as established contributors. Remote collaboration can be a powerful tool to build working relationships that will achieve that end.

Fundamentally, to achieve the most ambitious goals for remote collaboration, international governmental arrangements whether bilateral, multilateral (using organizations like the IEA), or collectively between entities such as the IEA and ITER, are needed so that the resources are available to test, explore and successfully implement this concept.

INTRODUCTION

experiment. A common set of tools and interfaces is required for integration and evaluation in a real-world operations environment. Implementation of such a system has the dual benefits of creating a testbed for remote collaboration tools and concepts and providing a world-class environment for collaborative research in fusion science.

Over the next 5-10 years enhancing and distributing the needed technology of remote collaboration may be the most pressing priority. A common set of tools and interfaces is required for integration and evaluation in a real-world operations environment. To test and incorporate these technologies into the research environment will require commitments by national and laboratory programmatic leaders and the attention and interest of the working level scientist. Within a decade, however, technology may simply be *there*, driven by more general societal forces that demand a level of access and interaction now unachievable for cost or technical reasons. The most productive role played by the current participants in relation to technical needs may be to seed, shape and stimulate the emergence of elements of that telecomunications software/hardware technology portfolio which fill in the niches needed for successful research collaborations.

In parallel, a variety of management and social issues ranging from assuring remote participants are accepted as full research partners, determining the division of operational responsibility, to intellectual property rights, are almost certain to emerge as equally compelling challenges. To address these issues, there will be no substitute for thoughtful experience. That will require recognizing the existence of these issues and spending some level of effort examining and then testing solutions. A dialogue among members of the fusion and science community about these topics will be particularly critical, since management and social elements of research rarely command the interest of scientists.

Current Experience

The magnetic fusion research community has considerable experience in placing remote collaboration tools in the hands of real users. The ability to remotely view operations and to control selected instrumentation and analysis tasks has been demonstrated. In the U.S. the University of Wisconsin scientists making turbulence measurements on TFTR[1] were provided with a remote control room from which they could operate their diagnostic, while keeping in close contact with their colleagues in Princeton. LLNL has assembled a remote control room in Livermore in support of a large, long term collaboration on the DIII-D tokamak in San Diego[2]. From the same control room, a joint team of MIT and LLNL scientists has conducted full functional operation of the Alcator C-Mod tokamak located 3,000 miles away in Cambridge Massachusetts[3]. In Europe, Belgium, Germany and the Netherlands, the Trilateral Euregio Cluster, are establishing the basis for an international but intra-european remote collaboration using TEXTOR experiment as its experimental focal point. A connection between Berlin and IPP-Garching has tested remote control of an ASDEX diagnostic. Connections between the JT-60U tokamak in Japan and PPPL and LANL in the U.S., as well as the multi-site ITER have led in the general direction of consolidation and focusing of national (and international) fusion research programs onto fewer high-performance devices at widely separated sites. For example, the current generation of US experiments are explicitly "national facilities" with advisory committees made up of experts from outside laboratories, each with a host of collaborators participating in their experimental programs. This serves as a strong motivating force to remove technical barriers for collaborating scientists and to improve the efficiency of joint research. Researchers should be able to move their research easily from machine to machine with a minimum of travel and expense and without the need to constantly learn new tools and techniques. This development must be undertaken jointly to provide, as far as is practical, a common collaborative environment for all existing facilities.

REQUIREMENTS

The requirements have been divided into five subsections. The first relates to the fundamental program decisions required for any ambitious use of remote collaborations. The next three subsections address functions to be performed - Experimental Operations, Data Analysis and Planning and Coordination. The final subsection is a discussion of sociological considerations and issues associated with any large collaboration.

1. Policy Actions

1.1 National and International Approaches

Currently, network capacity at an affordable price limits the extent of international connections. Prices are likely to come down with new capacity added rapidly, changing the present environment. Nevertheless, without agreement at the national program and laboratory leadership level that remote collaboration is valuable, the resources, both human and financial (technology) will not be available in a timely fashion.

Initiatives at the laboratory level will be most critical at this juncture since many of the key tests of the concept can take place between domestic collaborators, with existing infrastructure and experiments. Nevertheless, support at the national program level will be essential to confirm the appropriateness of the laboratory leaders decisions and to provide direction and funding for future, more ambitious undertakings, especially with international partners. Even at this juncture modest actions on an international level based on laboratory initiatives are possible.

When remote collaboration reaches the international level there is still a role for laboratory support for purchasing equipment or capacity for international connections. However, an active international program will require a stronger commitment on a national program level. Decisions at the national or in the case of the European Community multinational government program level are essential to provide sufficient resources and the appropriate legal framework to formal agreement on issues such as access to data and remote operation. The integration of the remote collaboration concept into the project will have to be agreed upon by the international partners prior to construction, perhaps as part of a specific agreement and certainly identified and specified with the final engineering design. It will be critical to assure that the facility design incorporates the design features that support the concept and avoid any engineering approaches that complicate implementation.

1.2 World Participation

Remote access and remote participation are logical tools that can enlarge the participation in fusion research around the world and improve its effectiveness. Since the research activities in various developing nations vary from small university groups and individual researchers to growing programs in nations such as India, China, Korea, the ability to use remote participation will vary over a considerable range. In some cases electronic journals and access to databases or software tools will meet the need, facilitating modest research activities. In others, individual researchers or small groups may find a niche where they can play a valued role in larger programs supported by remote collaboration technology. In still others, nations with emerging fusion programs may seek closer working relationships with experienced national programs, using telecommunications to reinforce the relationship and provide access to databases and standardized software.

Nevertheless, to extract the maximum benefit from these various forms of collaboration will require a minimum level of telecommunications infrastructure. One step that can be undertaken is a survey of current telecommunications resources of interested participants to identify current needs. This information can be used as a basis for requesting domestic support or for developing proposals to international organization such as the IAEA.

2. Requirements for Experimental Operations

Current fusion energy experiments are run in pulsed mode, with typically 3-6 plasma discharges (shots) per hour, each of several seconds duration. In the 10-20 minutes between shots, all data is acquired, stored, and readied for display utilizing some preliminary analysis results. Raw and processed data are evaluated, and decisions are made concerning the "success" of the current shot and plans for the next. Required changes for tokamak operation and diagnostic configuration must be implemented and the next cycle begun.

For effective remote operation, tools and technologies must be implemented that create a remote operations environment as similar to the local environment as is practical. These tools and technologies need to provide, in real-time, information on current machine state and status and display of experimental data at the local and remote sites. Historical and summary shot data must also be readily available. Finally, functionality for remote control and monitoring is required.

more limited quality video. This has the advantage of reducing bandwidth requirements or allowing for out-of-band (namely telephone) implementations. In the long run, tools that support multiple (n-way) conferences with improved control and monitoring functions are required. These include the ability to participate in ongoing conversations, to add or drop participants, to allow break-through broadcasts of important announcements and to insure privacy where it is needed.

2.2 Status and Summary Information Display

An essential suite of applications provides an interface to the experiment "state" so that all researchers can determine the status of experimental operations. This information is available locally on large central displays, on desktop computers, and via local networks. Typically, an announcement of an impending shot followed by a countdown to the next shot or a change in machine state is broadcast over a public address system. At a remote site, these displays and pertinent announcements need to be replicated. The visual information must be provided on remote computers via a standardized interface such as WWW-based software or X-windows displays, with the audio announcements mixed into the available A/V channels. Applications should also track the shot summary and operating parameters of the current run. An electronic notebook like application, with a "view" of the machine operator's log, would provided the required functionality. Local and remote experimenters should also be able to make their entries into the common "notebook". As each new entry is made, the display would be updated.

2.3 Remote Experimental Control

In order to allow remote collaborators to actively participate in fusion experiments, they need full access to the monitor and control information and the ability to feed information back to the experiment site and to other remote participants.

Collaborators responsible for operating diagnostic or machine systems require full remote control capabilities. Those responsible for directing the physics program need good communication with the local support staff, along with the ability to monitor the status of many systems in order to optimize operation and data output. Participating researchers also need tools for viewing the status of tasks on various servers which are acquiring and analyzing data. Although many features of required monitoring and control tasks are in place and easily run over the network via X protocols or remote procedure calls, enhancements to provide platform independence and more uniform interfaces are required.

Security is an absolute necessity for remote control. Alternatives for protecting these processes must be evaluated and adequate controls implemented before complete remote experimental control can become an operational norm.

3.0 Requirements for Data Analysis

level of interaction is required. Some programs run immediately and produce graphics output which is available during or shortly after a shot. Between shot programs may require more computational power or may depend on receiving results from programs which have run previously. Sophisticated analysis tasks may complete several shots or even days later. Some analysis is performed using single computer systems, while other analysis is best performed by taking advantage of any distributed computing resources which might be available.

The fusion community's computing requirements call for what is conventionally visualized as a distributed computing environment. There is a strong need for transparent, high speed access to distributed data and software and efficient use of distributed computing resources. This includes the ability to easily communicate between distributed tasks and the need for access to distributed printing and graphics services. Underlying these requirements is need for high speed networks and a need or security.

By necessity, any solution must be at minimal cost and require minimal maintenance.

3.1 Shared Code Development

In the context of remote collaboration, shared development of codes and the promotion of standards and compatibility among exiting fusion codes is a clear requirement. This by itself is one of the strongest requirements for distributed file systems such as DFN which is currently available. The ability to easily relink complex codes using common libraries has become a more or less standard approach within the fusion community. Also, because users are not co-located, friendly code management software becomes a necessity. Within the U.S. a Fusion Science Computing Committee has been formed to address standardization and compatibility with the hope that this would be expanded in a world effort.

3.2 Distributed Data Access

Of equal importance to the ability to jointly develop software is the ability to share access to data from experiments, analysis results, and modeling. This requires global, secure access to data from all collaborating sites. It is important, however, to note the existence of legacy systems for each of the currently operating experiments (the DIII-D, TFTR, and Alcator C-Mod, JET, JT-60U, ASDEX-UG tokamaks, Wendelstein 7-AS, CHS stellarators, etc.). The necessity for maintaining these systems will strongly impact any technical approach to be used for distributed data access.

Technology for distributed data access is rapidly developing. Our requirements in this area include efficient network access to large files and small fractions of files, security and authentication, integration of legacy systems, portability and easy maintenance. Three examples are the distributed file systems, client server, and distributed objects approaches.

Tasks also need to be able to provide displays of results to remote users and printout results in accessible locations. Distributed queuing is needed to handle initiation of tasks when the right conditions are met. Standardization of these services across the various collaborating laboratory environments is required.

3.4 Security

Security is a requirement to protect the data and software from advertent or inadvertent alteration and to ensure that inappropriate access is not granted,n while allowing shared updates as necessary. Inappropriate access is normally expressed as a concern that someone will attempt to hastily interpret, publish or criticize data or results before knowledgeable researchers have had an opportunity to fully analyze and verify results.

4. Requirements for Planning and Coordination

Effective communications among a small number (typically ~2-5) of collaborators at different locations remains one of the most important requirements for successful fusion collaborations. Various components of such communication are audio, video (including fixed and controllable sources, voice-activated view switching, etc.), and document sharing (whiteboards, screen sharing, shared applications).

Large group interactions have a somewhat different set of collaborative requirements. For larger groups, prearranged meetings are the preferred method for interaction. Some of these meetings are currently being regularly broadcast using internet and ISDN based videoconferencing tools.

Additionally, several specialized tools to enhance remote communications, such as electronic notebooks, indexed recording and replay and electronic scheduling, are required.

The interfaces to all of these tools need to be clean, simple, and intuitive, and the reliability of the tools needs to be excellent. Researchers don't have the time to spend debugging collaboration tools or figuring out how to operate a complex piece of software. Spontaneity is required for successful research and things that aren't reliable and easy to operate won't get used. Near-identical interfaces to similar tools at various institutions would greatly enhance the effectiveness of the researcher shifting between machines.

4.1 Small Group Interactions

Good audio tools are perhaps the most important requirement for the support of small group collaborations. The requirement is for reliable, hands free, full duplex audio which allows free discussions as if the people were all present in the same room. Problems such as echoes and audio clipping must be handled gracefully. People need to be able to enter and leave the conversation at will; those involved in activity as if it were a "look around the control room".

White board tools are also required which allow text and simple diagrams to be drawn, marked up and shared among collaborators. The white board needs to easily import text and graphics from any window. Shared views of applications, displays, and documents incorporated with the white board tools are required to enable the shared use of control programs and other relevant applications. To see and talk to a collaborator and say "let me show you..." makes the shared view approach a very powerful addition to remote collaboration experience and is required to give the remote collaborator the feeling of full inter-actively and equality with those present locally.

Once tools for small collaborations have been improved, small areas in the control room and around the laboratories need to be equipped and designated as "chat corners". These "chat corners" would allow impromptu meetings between remotely located collaborators. Such impromptu meetings can be critical to promoting successful research.

4.2 Large Group Interactions

The audio for large group meetings needs to be expanded to allow for improved multi-point communication with support for interactive discussion. These means that reliable, hands free, full duplex audio is required for these meetings. Again, echo cancellation and audio clipping should be handled easily. There must be a mechanism permitting smooth and equitable microphone sharing, so that remote personnel can participate as well as listen. Broadcasts from large meeting rooms require special equipment to ensure that the audio from all participants can be picked up and transmitted clearly.

The video for these meetings requires better resolution than is currently being made available and the frame rates need to be improved to a minimum of several frames per second. All slides from the meetings need to be available electronically, whether drawn by hand or electronically. Support for multiple presentation formats, i.e. software-base view graphs, hardcopy presentation material, and sketches is required to maintain a free flow of information as currently exists in the informal working group meetings.

4.3 Recording; Indexed Replay

Substantial time differences between sites can make live participation in remote meetings difficult. Conflicting obligations at one's home institution can do the same, regardless of time zone. Such difficulties lead to a need for recording and replay tools, with indexing features that permit easy access to relevant topics or to particular speakers.

4.4 Electronic Notebooks

4.5 Schedules; Experimental Run Plans
All relevant schedules for machine operation including the tokamak, computer systems, auxiliary systems (e.g. plasma heating, diagnostics, etc.) and operation schedules should be available electronically in an easily accessible place. The Experimental Run plans should similarly be available. The Web appears to be a very natural place for these documents to reside.

5.0 Sociological and Management Considerations

Historically, fusion researchers have worked together in a collaborative manner. This, together with the implementation of the Distributed Collaborative Experimental Environment (DCEE) has provided experience with some of the sociological issues associated with the implementation of a remote collaboration environment.

5.1 Extended Environments

The ability of people to work together effectively is a social phenomenon; the ability of people to effectively work together when remotely located is a social phenomenon supported by technology. For example, time delays or technology limited visual clarity may obscure normal verbal and visual (body language) clues to meaning, requiring conscious adjustments in expectations and presentations to permit accurately capturing the intended message. Further understanding is needed of the relationships between people and their work environment, especially when the work environment is extended over large geographical regions that includes extensive implementation of communications technologies. Important issues are associated with working among people of different habits and cultures and people who have worked in just one environment and who must learn to adjust to working in several environments simultaneously.

5.2 Levels of Acceptance

a. Individual Researchers

Researchers are busy. In general to use and derive the full benefit of remote participation, whether as the remote researcher or the on-site collaborator requires TIME: time to define the problem to be addressed; time to acquire and learn how to use the software/hardware; time to develop the personal relationships needed to make the collaboration work; time to become familiar with the laboratory culture and physical environment. Inertia becomes a strong deterrent to beginning remote collaborations and so does management that think this activity is not a "real" part of the work. Thus while the theoretical benefits of the collaboration may be acknowledged, unless the most basic requirements of implementing and especially debugging the technical connections are "easy," as noted in the sections above, the barrier to participation will be high. In some cases, scientists responsible for data and communications, driven by very specific professional needs, or personal

may continue. Prior relationships are no guarantee of acceptance. A significant shift of perception about the value of carefully planned remote participation will have to take place to minimize this barrier. Without national and laboratory program leaders communicating acceptance of remote collaboration activities, initiating any activities may be perceived as risk taking. No one wants to be accused of "fooling around," instead of producing serious research results.
If acceptance by the host organization is difficult, support by the remote participants own organization can also be formidable. The level of effort required from the researcher to initiate remote collaboration activities can again be perceived of as a diversion, without enough compelling benefits.

c. Management Demands and Controls

While management demands for remote collaborations using individual diagnostics are not likely to be large, the requirements for well a define management organization should grow as the facility or scale of the work grows. The demands of operating larger facilities on the scale of ITER will be formidable.

The planning and direction of experimental sessions will require extensive negotiations among the Parties with a formal division of authority for any experimental session, an operational protocol especially for emergency situations, and an agreement on number and types of sessions directed by each of the Parties. The working relationships will have to be well developed, which means on-site visits as well as the availability of the tools for remote interactions described in previous sections.

The identification of critical safety systems will be essential for any remote operation scenario. Onsite control of these safety system would be expected.

d. Social Aspects of Security and Privacy

As technology improves, hearing and seeing every part of an operational area with increasing clarity and acuity will become possible. As sophistication of the communication technology progresses the comfort level of individual may diminish. At what point does observation becomes intrusion?

There needs to be a dialogue on the criteria for allowing outsiders, even colleagues, to see and hear a conversation. Enough professional but sensitive conversation take place that temporarily blocking access to certain camera positions and audio may be appropriate an option to consider. Unfortunately, that type of personal control can disrupt the open environment and the use of selective blocking create its own disruptions.

e. Intellectual Property

International agreements normally handle all the legal issues related to patents and other intellectual property. The more sensitive questions normally arise with on-going sociological study will help to define some of the directions or modifications to the technical environment.

5.2 Common Language

The vocabulary used by collaborators is an important issue for the remote collaboration environment. Currently, each facility has evolved its own vocabulary. An experimenter who begins work at one facility must learn the idiosyncrasies of the local vocabulary (jargon) and how to translate as he or she moves to or collaborates at another facility. An important requirement for establishing effective collaborations is to create a method to eliminate as many of the language differences as possible yet retain a diversity of expression. For example, the names for similar data must become part of a common vocabulary.

SUMMARY OF REQUIREMENTS

1. Requirements for Actions
    - Support from Laboratory / Program Leaders
    - National Commitments for Implementation
    - International Agreements and Supporting Organization(s)
    - Integration in Shared Large Projects
    - Effective Use of World Resources

2. Requirements for Experimental Operations
    - Control Room Audio and Video
    - Status and Summary Information Display
    - Remote Experimental Control

3. Requirements for Data Analysis
    - Shared Code Development
    - Distributed Data Access
    - High Performance Computing
    - Security

4. Requirements for Planning and Coordination
    - Small Group Interactions
        - Audio Conferencing
        - Video Conferencing
        - White Boards
        - Chat Corners
    - Large Group Interactions
        - Multi-point Audio
        - Multi-point Video
    - Recording, Indexed Replay
    - Electronic Notebooks
    - Scheduling; Experimental Run Plan

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